



Giant piezoelectric response in bulk single crystal relaxor ferroelectrics such as $\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{-PbTiO}_3$ (PMN-PT) and $\text{Pb}(\text{Zn}_{1/3}\text{Nb}_{2/3})\text{-PbTiO}_3$ (PZN-PT) have propelled these materials to the forefront of research for piezoelectric devices. A major challenge is to prepare these materials as "single crystal" epitaxial films between electrodes and integrate them with silicon so that their properties can be utilized in piezoelectric devices with all the advantages of microelectronic technology. There are several advantages to growing these films on silicon: (1) integration of functional materials with silicon-based electronic circuits (e.g., MOSFETs), (2) the possibility of utilizing well-developed device fabrication process for the patterning of silicon, and (3) large area and high-density device fabrication.

We have fabricated epitaxial PMN-PT piezoelectric heterostructures on "silicon" with superior piezoelectric properties. PMN-PT films are grown on $\text{SrRuO}_3/\text{SrTiO}_3/(100)\text{Si}$ substrates. The SrTiO_3 seed layer (70-150Å thick) is deposited by molecular beam epitaxy (MBE) by Darrell Schlom at Penn State University. The overlaying SrRuO_3 metallic oxide electrodes (100 nm) are deposited by off-axis sputtering. SrRuO_3 is an ideal bottom electrode for epitaxial piezoelectric heterostructures since it is a conductive perovskite with an excellent lattice mismatch with PMN-PT. Finally, the PMN-PT films are deposited by RF magnetron sputtering. X-ray diffraction, cross-sectional TEM micrographs (a) and selected electron diffraction (b) show these PMN-PT films are purely c -axis oriented texture. The longitudinal piezoelectric coefficients (d_{33}) were measured using scanning force microscopy. When subdivided the capacitors with lateral dimensions in the 0.5-3micron range by focused ion beam processing to reduce mechanical constraints (c), the 4 μm thick PMN-PT film shows a longitudinal piezoelectric response, d_{33} of 700 pm/V which is the highest value ever reported in thin films (d). This epitaxial heterostructure has a great potential for multilayered microelectromechanical systems (MEMS) devices with high strain and low driving voltage for miniature devices, high frequency ultrasound transducer arrays for medical imaging, tunable dielectrics, and capacitors for charge and energy storage.